Characterization of convection-related parameters by Raman lidar: Analysis of selected case studies from the Convective and Orographically-induced Precipitation Study

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ABSTRACT

This work illustrates an approach to determine the convective available potential energy (CAPE) and the convective inhibition (CIN) based on the use of data from a Raman lidar system. The use of Raman lidar data allows to provide high temporal resolution (5 min) measurements of CAPE and CIN and follow their evolution over extended time period covering the full cycle of convective activity. Lidar-based measurements of CAPE and CIN are obtained from Raman lidar measurements of the temperature profile and the surface measurements of temperature, pressure and dew point temperature provided by a surface weather station. The approach is tested and applied to the data collected by the Raman lidar system BASIL in the frame of the Convective and Orographically-induced Precipitation Study (COPS). Attention was focused on four selected case studies: 19 June, 30 June-1 July, 14-15 July and 25-26 July, with a specific focus on 15 July 2007. Reported measurements are found to be in good agreement with simultaneous measurements obtained from the radiosondes launched in Achern and with estimates from different mesoscale models.

BASIL LIDAR SYSTEM

The University of BASILicata Raman Lidar system (*BASIL*) was deployed in Achern (Black Forest, Germany, Lat: 48.64 °N, Long: 8.06 °E, Elev.: 140 m) in the frame of the Convective and Orographically-induced Precipitation Study (COPS, Wulfmeyer *et al*., 2008; Richard *et al*., 2009, Kottmeier *et al*., 2008; Kalthoff *et al*., 2009). During COPS, BASIL operated between 25 May and 30 August 2007 and collected more than 500 hours of measurements, distributed over 58 measurement days and 34 intensive observation periods (IOPs).

Fig. 1 Lidar System during COPS campaign

INTRODUCTION

In order to indicate the potential for severe weather events, the convective available potential energy (CAPE) and the convective inhibition (CIN) can be determined. Esimates of CAPE and CIN are traditionally determined from radiosonde data. The present work proposes an approach to measure CAPE and CIN based on the use of lidar measurements of the temperature profile and surface measurements of temperature and dew point temperature. The convective inhibition index (CIN) is the energy that has to be provided to an air parcel in order to lift it vertically and dry-adiabatically from its initial position to its lifting condensation level (z_{LCL}) and then pseudo-adiabatically to its level of free convection (z_{LFC}). CIN represents the amount of negative buoyant energy available to inhibit upward vertical air acceleration. The largest is CIN the stronger must be the amount of forced lift to bring the parcel to its z_{LFC}. CIN can be defined as:

$$CIN = \int_{z_0}^{z_{LFC}} g \frac{T_p(z) - T(z)}{T(z)} dz \; [J / kg_{ARIA}]$$

where the term represents the buoyant force per unit mass, with g being the gravitational acceleration (9,8076 m s-2), $T_p(z)$ being the air parcel temperature at altitude z, and T(z) being the environmental temperature at altitude z; z_0 is the surface altitude. CIN can be calculated by vertically integrating a local buoyancy of the lifted air parcel from z_0 to z_{LFC} (red region in Fig. 2).
Once z_{LFC} is reached by the lifting air parcel, CAPE can be released. CAPE is defined as:

$$CAPE = \int_{zLFC}^{zEQL} g \frac{T_p - T}{T} dz \quad [J / kg_{ARIA}]$$

and can be calculated by integrating vertically the local buoyancy of the lifted air parcel from z_{LFC} to the equilibrium level(z_{EQL}) (green portion in Fig. 2).

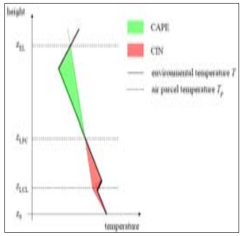

Fig. 2: Schematic diagram representing the convection indices.

CAPE represents the positive buoyancy of the air parcel and is an indicator of atmospheric instability to a finite vertical displacement. CAPE is widely used to quantifies the maximum possible intensity of convection (Emanuel, 1994): the larger is CAPE, the larger is the energy available for the formation of thunderstorm cells.

CIN VALUES	WHEATER CONDITION
CIN <50 [J/Kg]	Weak cape that can be easily broken by surface heating
50<CIN<200 [J/Kg]	Moderate cap that can be broken by strong heating/synoptic scale forcing
CIN > 200 [J/kg]	Strong cap that prevent convection in the atmosphere and impedest hunderstorm evelopment.

CAPE VALUES	WHEATER CONDITION
CAPE <1000 [J/Kg]	Weak instability
1000<CAPE<2500 [J/Kg]	Moderate instability
CAPE > 2500 [J/kg]	Strong instability

Tabel 1: Schematic Values for CIN/CAPE

To compute both CAPE and CIN a proper estimate of the lifting condensation level z_{LCL} is required. This is obtained from the surface values of atmospheric temperature, T(z0), and dew point temperature, TD(z0), for the purpose of this work provided by a surface weather station. The dry-adiabatic lapse rate Γd has a constant value equal to –g/cp (0.009769 K/m), with cp being the specific heat at constant pressure (1004 J kg−1 K−1), while the pseudo-adiabatically lapse rate Γs(z) varies with altitude and has a more complex formulation, which will be discussed at the conference, primarily dependent on the atmospheric temperature profile.

RESULTS AND DISCUSSION

We focused out attention on IOP on 15 July 2007, which was dedicated to the study of locally initiated convection or air-mass convection. (Kottmeier et al., 2008).
On 15 July 2007 deep convection developed on an area east of the Black Forest crest (Richard *et al*., 2011), although convective available potential energy was only moderate and convective inhibition was high in most of the COPS area. Data analysis revealed that synoptic forcing was absent and convection was triggered by different mechanisms.
Fig. 3 illustrates the time evolution of the water vapour mixing ratio over a period of ~ 15 hours from 04:50 to 20:00 UT on 15 July 2007. The figure covers the daytime portion of the measurement record with noisy data above approximately 3-4 km. Fig. 3 is plotted as a succession of 5 min averaged consecutive profiles.

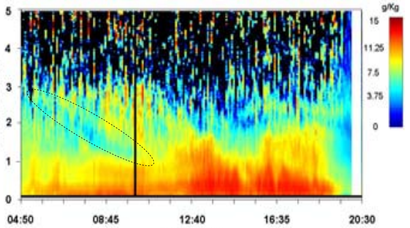

Fig. 3: Time evolution of *BASIL* water vapour mixing ratio from 04:50 to 20:00 UT on 15 July 2007. The dashed ellipse highlights the presence of a dry layer acting as a lid and inhibiting convention.

Fig. 4 illustrates the vertical profile of T and Tp, as obtained from data collected by the radiosonde launched in Achern at 10:59 UTC on 15 July 2011. The values of CAPE and CIN determined from the radiosonde data are 104 and -354 J/kg, respectively. The values of zLCL, zLFC and zEL obtained from the radiosnde data are 1662 m, 3293 m and 5884, respectively. Values of CAPE and CIN obtained for this same radiosonde launch obtained by Kalthoff et al. (2009) are 90 and -327 J/kg, respectively, while those obtained by Barthlott et al. (2011) are 86 and -219 J/kg, respectively.

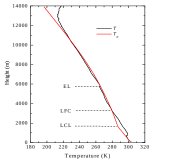

Fig. 4: Vertical profile of *T* and T_p, as obtained from data collected by the radiosonde launched in Achern at 10:59 UTC on 15 July 2011.

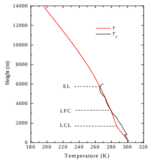

Fig. 5: Vertical profile of *T* and T_p, as obtained from the Raman lidar averaged over the time period 11:00-11:30 UTC on 15 July 2011.

Fig. 5 illustrates the vertical profile of T, as measured by the Raman lidar, averaged over the time period 11:00-11:30 UTC on this same day (values above 6.1 km are not reported because affected by large random uncertainties); the figure also illustrates the vertical profile of T_p, as determined from Γ_d and $\Gamma_s(z)$, this latter being estimated through expressions the algorithms described above, based on the Raman lidar measurement of T and the surface weather station measurements of T(z0), p(z0) and TD(z0), for the same time period. Values of z_{LCL}, z_{LFC} and z_{EL} are 1637 m, 3200 m and 5900 m, respectively, in good agreement with those determined from the radiosonde data.
The values of CAPE and CIN determined from the lidar measurements in Fig. 5 are 92 and 360 J/kg, respectively, again in good agreement with those determined from the radiosonde data.

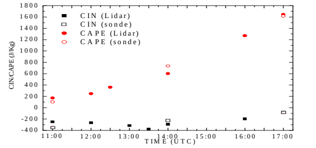

Fig 6: Evolution of CAPE and CIN as over the time period 11:00-17:00 UTC on 15 July 2007 determined from the radiosonde and the lidar measurements.

Fig. 6 illustrates the evolution of CAPE and CIN as over the time period 11:00-17:00 UTC on 15 July 2007 determined from the lidar measurements. Values of CAPE are found to grow during the morning (up to approx. 1700 J/kg at 17:00 UTC) as a result of the increasing temperature and moisture in the PBL and the accumulation of potential convective energy. However, late in the morning and in the afternoon values of CAPE were only moderate and CIN was high (with slightly varying values around 200-300 J/kg). The high values of CIN inhibited deep convection on this day.
Values of CIN and CAPE obtained from lidar and the radiosonde can also be compared with estimates from different mesoscale models. While the value of CAPE at 14:00 UTC from lidar is is 601 J/kg and from the radiosonde is 723 J/kg, corresponding value from WRF UK, Méso-NH, AROME and COSMO DLR are 711, 684, 664, 659 J/kg, respectively (Barthlott et al., 2011)

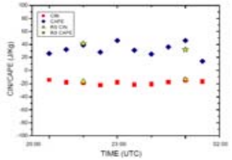

Fig. 7: Evolution of CAPE and CIN as over the time period 20:00-02:00 UTC on 25-26 July 2007 determined from the radiosonde and the lidar measurements.

The above mentioned procedure was also tested for a night-time case study. Fig. 7 illustrates the evolution of CAPE and CIN as over the time period 20:00-02:00 UTC on 25-26 July 2007. Values of CAPE and CIN keep stable and low as expected for convection free night –time conditions.

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